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SOLAR OBSERVATIONS FROM THE P78-1 SATELLITE.(U)

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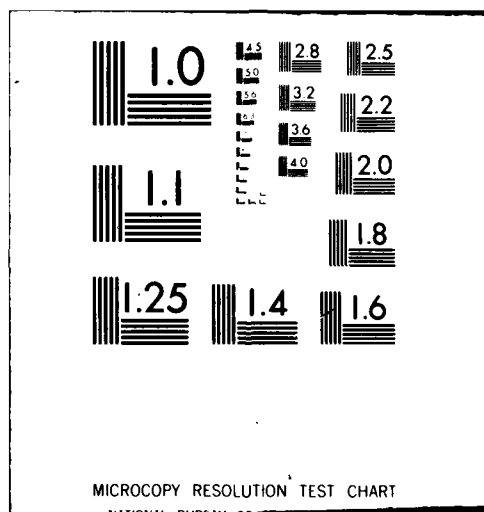
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## Solar Observations from the P78-1 Satellite

P. B. LANDECKER and D. L. McKENZIE  
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15 February 1982

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This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

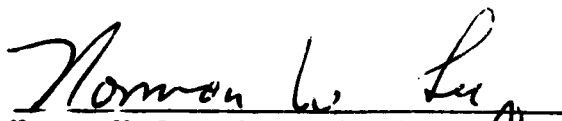


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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  Five experiments on the P78-1 satellite have been recording solar data from February 1979 to the present time (August 1981). The SOLEX X-ray spectrometer/spectroheliograph experiment is a pair of collimated Bragg crystal X-ray spectrometers (3-25 Å). The MONEX monitor X-ray experiment uses two uncollimated X-ray proportional counters (0.05 through 12 Å). The SOLFLEX solar flare X-ray experiment uses four uncollimated Bragg crystal X-ray spectrometers near 1.9, 3.0, 3.2 and 8.4 Å. The MAGMAP magnesium mapping experiment uses two filtered proportional counters which view the sun through the SOLEX 60 arc sec		

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collimator (8-12 Å). SOLWIND is a white light coronagraph viewing from 2.5 to 10 solar radii. These five payloads are described, then sample data from each are given and interpreted. The data permit measurements of solar flare plasma densities, temperatures, emission measures, dimensions and velocities as well as the mass releases and velocities in the sun's outer corona. References to major P78-1 solar publications are also given.

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## I. INTRODUCTION

The P78-1 satellite was successfully launched on 24 February 1979. The solar experiments, located in the pointed despun section of this satellite, are currently operational and continue to collect important data about the evolution of solar active regions, flares, and coronal transients, with excellent spatial, spectral, and temporal resolution [1]. A review of these experiments and their results is presented.

## II. SOLEX

The SOLEX solar X-ray experiment is a spectrometer and spectroheliograph. The SOLEX A channel consists of a 20 arc sec FWHM multigrid collimator, a flat RAP ( $2d = 26.12 \text{ \AA}$ ) or ADP ( $2d = 10.64 \text{ \AA}$ ) Bragg crystal, and a proportional counter detector. SOLEX B contains a 60 arc sec FWHM multigrid collimator, a flat RAP or ADP Bragg crystal, and a CEMA (channel electron multiplier array) detector. As shown in Figure 1, two pairs of crystals are located on a single shaft and are mounted back to back so that either type of crystal can be positioned behind either collimator. The crystal drive stepper motor rotates the shaft in 30.2 arc sec steps 31.25 or 62.5 times a second. The collimator design approach and the crystal measuring techniques are described in reference [2], the CEMA detector system in reference [3], and the entire payload in references [4-7].

SOLEX can operate in the spectrometer mode. The spacecraft solar-pointed section is directed to an interesting point on the solar disk. The crystals scan back and forth between pairs of end points programmable by ground commands. Spectra in the 3 through 25  $\text{\AA}$  range are thereby recorded and about 200 lines have been identified [8,9]; these include lines from Cr XV-XVIII and Ca XV-XVIII [10]. SOLEX data were used to obtain the differential emission measure in the range 2 through  $18 \times 10^6 \text{ K}$ , as well as the total emission measure, the radiative loss rate, the electron density and the conductive cooling time [11]. SOLEX can also operate in the spectroheliograph mode. For this case, the crystal position is fixed at a selected wavelength, and the satellite solar-pointed section is made to generate large raster (45 arc min  $\times$  45 arc min) patterns, in order to survey the entire solar disk, or small

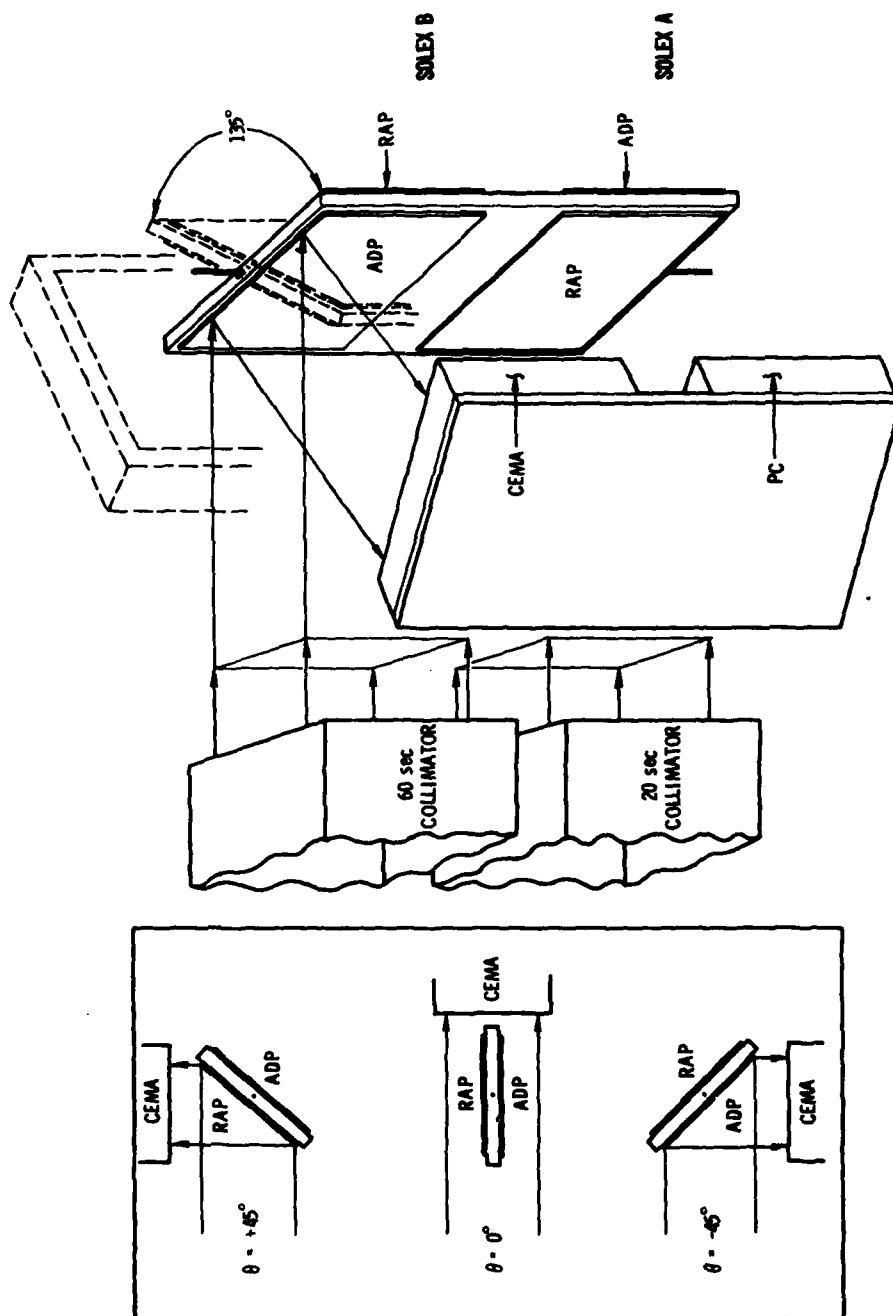


Fig. 1. Layout of the SOLEX Collimators, Crystals, and Detectors. Solar X-rays enter this experiment from the left.

raster (5 arc min  $\times$  5 arc min) patterns, in order to study a single active region. Each large and small raster takes 491.52 or 61.44 sec, respectively. These raster operations are illustrated in Figure 2. Raster wavelengths in the 3 through 25 Å range are selected by ground command and monochromatic solar X-ray maps are thus generated.

A typical sequence of SOLEX B spectral scans is shown in Figure 3. During this 8 April 1980 class M4 flare, SOLEX B was scanning repeatedly in the range 18.4 through 23.0 Å [12]. The ratio of the forbidden  $^3S_1$  to intercombination  $^3P_1$  line in the helium-like O VII triplet can be used as an electron density diagnostic [8,13], and results are shown in Figure 4. The volume emission measure,  $N_e^2 \Delta V$ , can be derived from the resonance line [12,14]. Since  $N_e$  is known, the number of particles  $N_e \Delta V$  and the volume  $\Delta V$  can also be determined as a function of time [12], and these results are shown in Figure 5. The electron pressure ( $P \equiv N_e T$ ) near  $2 \times 10^6$  K can then be calculated as a function of time.

A sample SOLEX B large raster, recorded later on the same day in the O VII resonance line, is shown in Figure 6. A sample SOLEX A small raster, recorded in 7.735 Å continuum starting at 9<sup>h</sup> 12<sup>m</sup> 12.3<sup>s</sup> UT during the class X5 solar flare on 20 August 1979, is shown in Figure 7. From a plot of the SOLEX A data recorded every 2.44 arc sec in azimuth, the spatial extent (FWHM) of the X-ray kernel was determined to be less than 28 arc sec [15]. This is the first soft X-ray measurement of the angular size of such an intense flare.

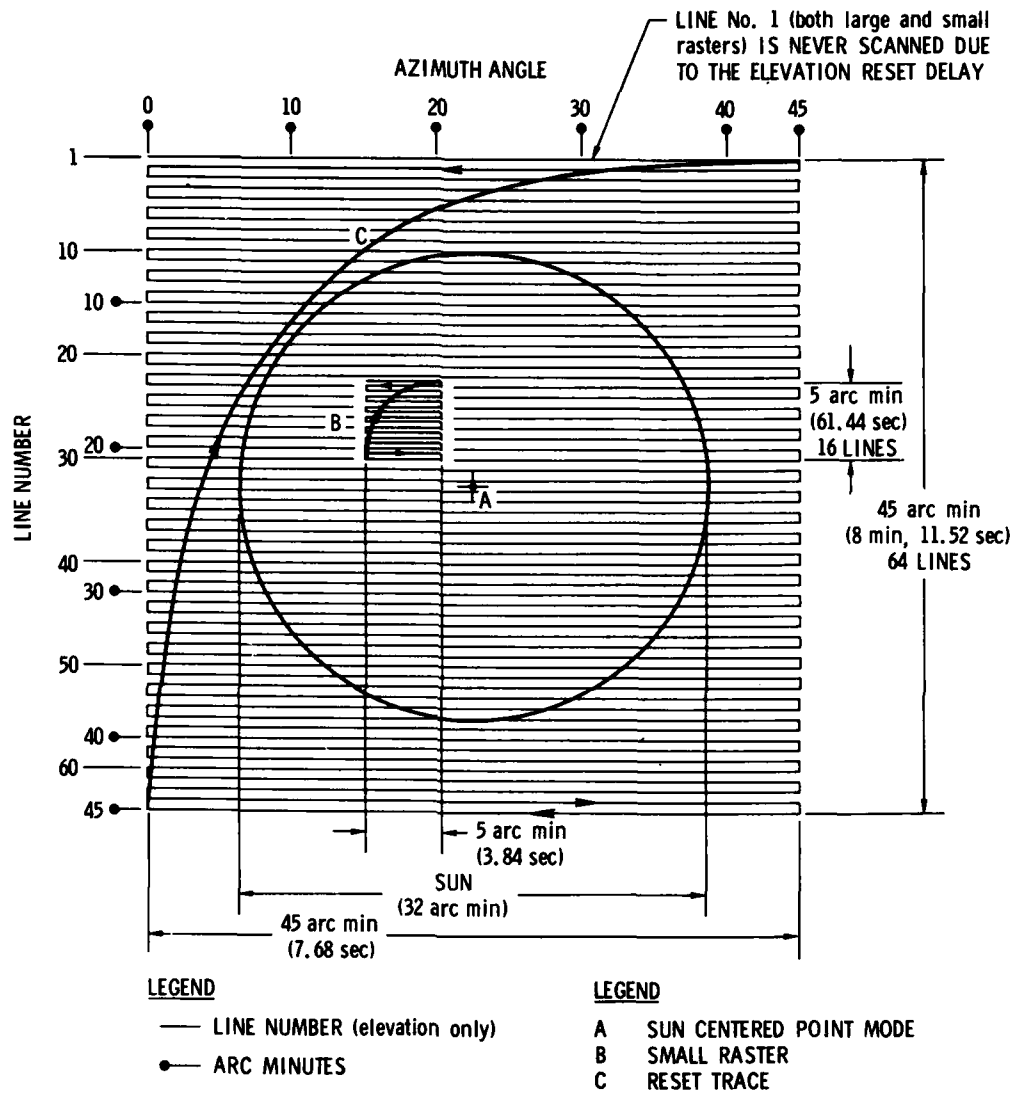


Fig. 2. The P78-1 Spacecraft Pointed Instrument Assembly Offset Mode Patterns. Large raster, small raster, offset point and sun center point options are available.

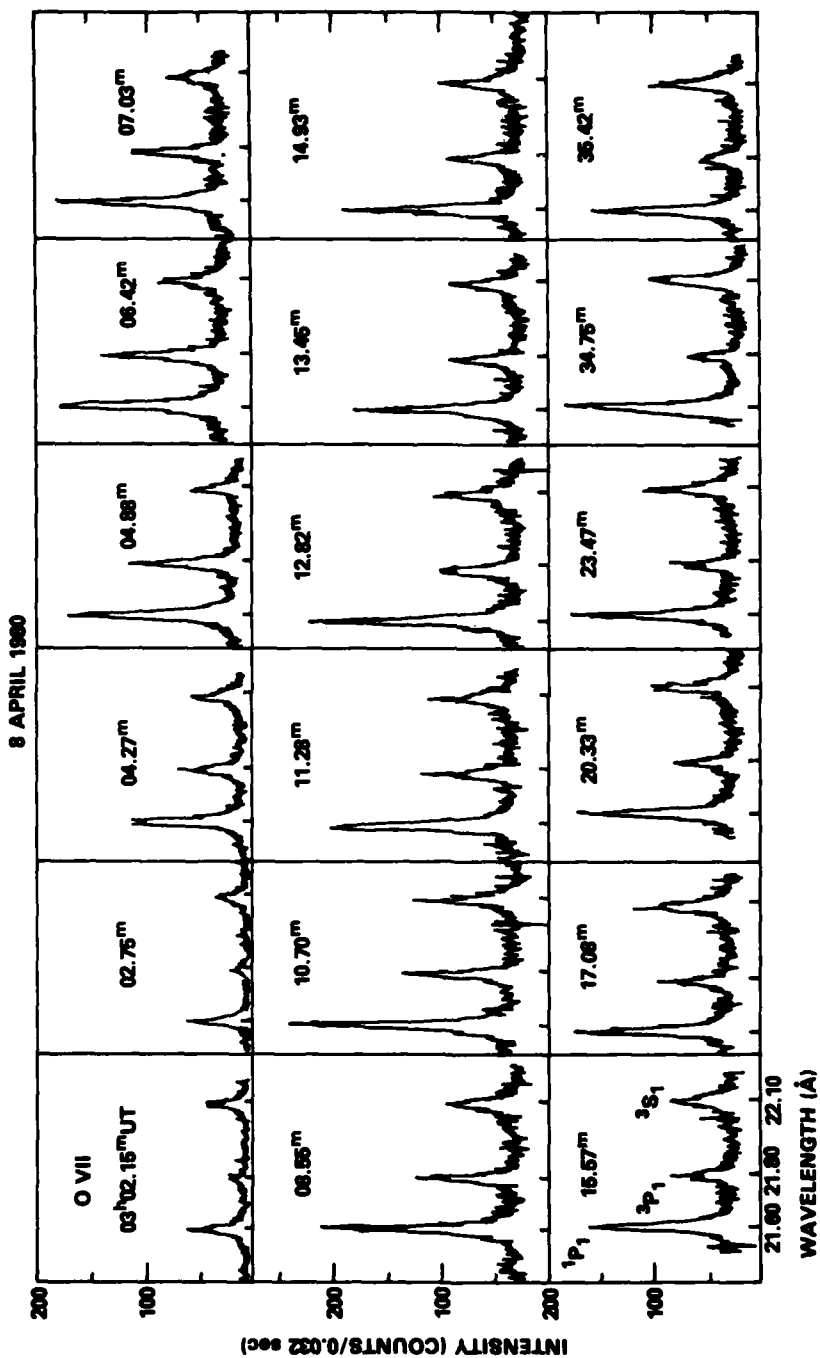


Fig. 3. Sample O VII SOLEX B Spectra for the 8 April 1980 Solar Flare. The times at which the  $1P_1$  resonance line was scanned are given in the upper part of each panel.

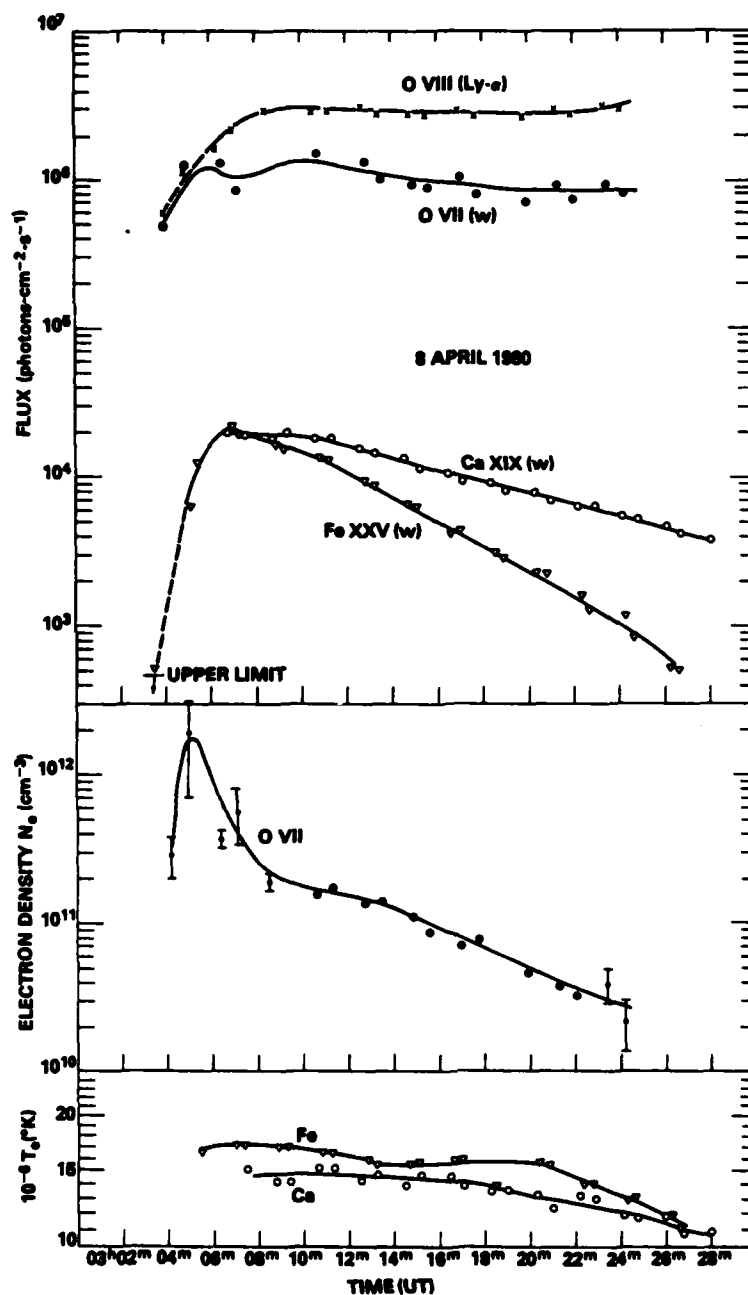


Fig. 4. Line Fluxes, Electron Density and Temperature, as a Function of Time for the 8 April 1980 Flare. The smooth curves are eye estimate fits to the data. Line w is the helium-like  $1P_1$  resonance line.



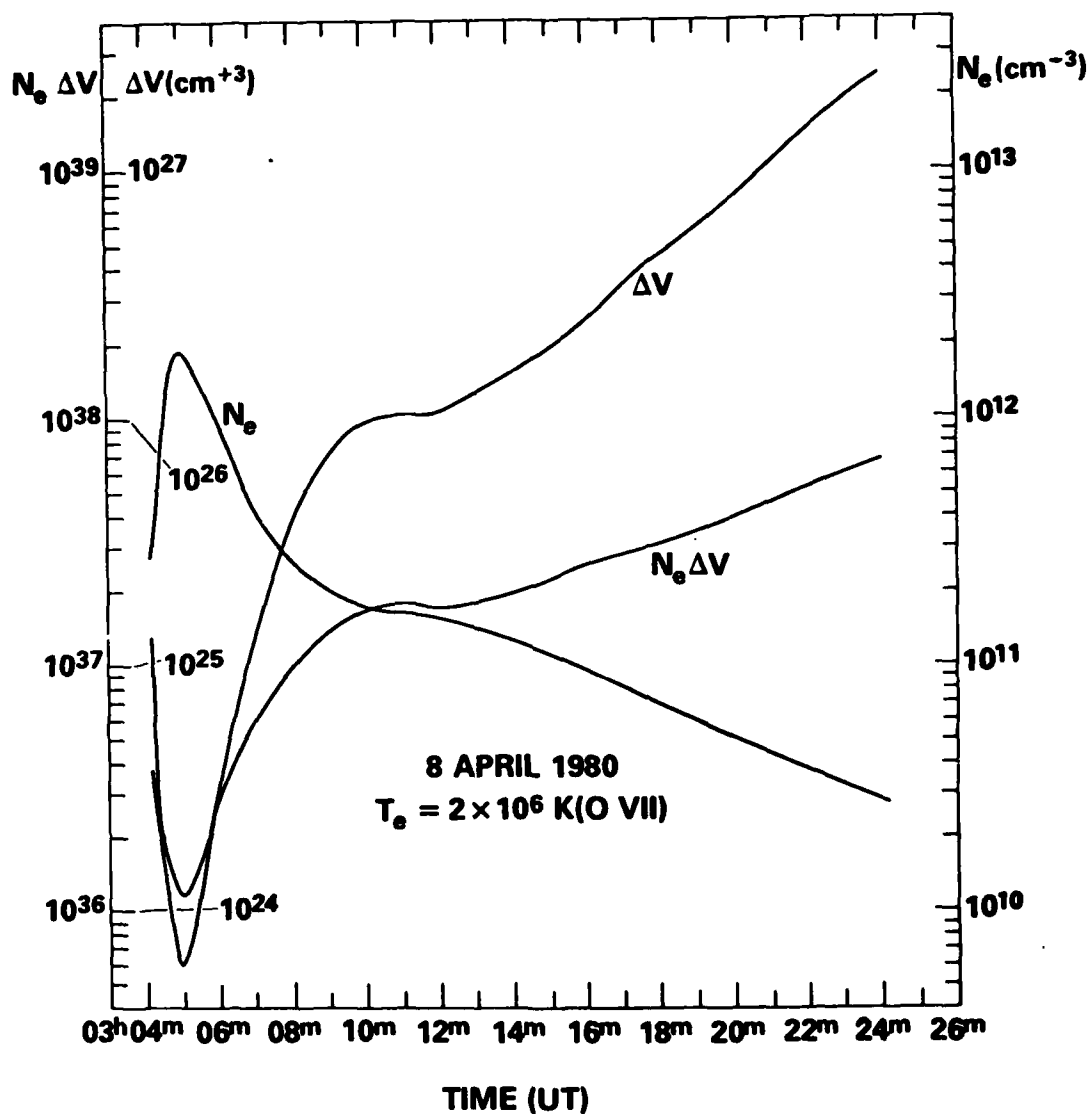


Fig. 5. Number of Electrons  $N \Delta V$  and Volume  $\Delta V$  as a Function of Time for the 8 April 1980 Flare. The volume  $\Delta V$  refers to the plasma volume in which the O VII line is emitted. The temperature of this plasma is about  $2 \times 10^6 \text{ K}$ . The electron density in this volume is also shown, adapted from Figure 4. The curves were obtained by using the smoothed curves for density and emission measure.

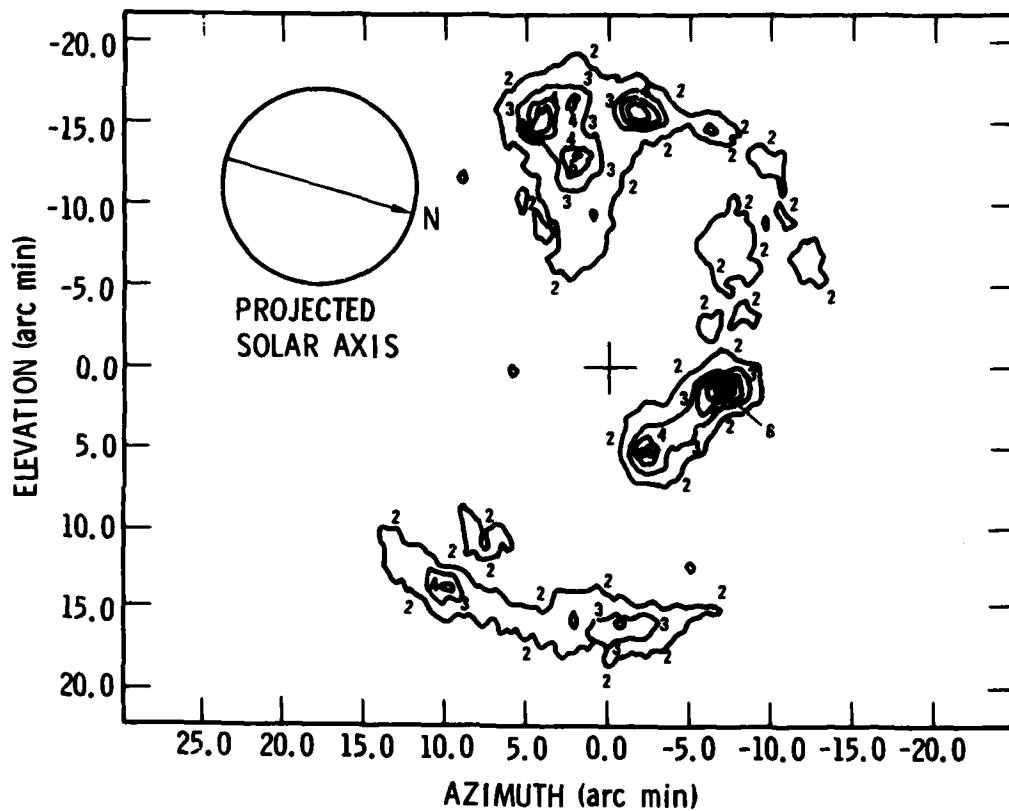


Fig. 6. Typical Nonflare Large Raster Map of the Entire Solar Disk in O VII  $1s^2 1S_0 - 1s2p 1P_1$  Resonance Line at  $21.601 \text{ \AA}$  Recorded with the 60 Arc Sec SOLEX B Collimator. This raster, consisting of 64 horizontal lines, started at the top of the figure at  $09^h 41^m 19.04^s$  UT on 8 April 1980 and stopped 491.52 sec later. The solar north direction is indicated. Elevation and azimuth scales in the figure are with respect to the center of the solar disk. Levels 2 and 6 correspond to 11 and 54 counts/32 msec, respectively.

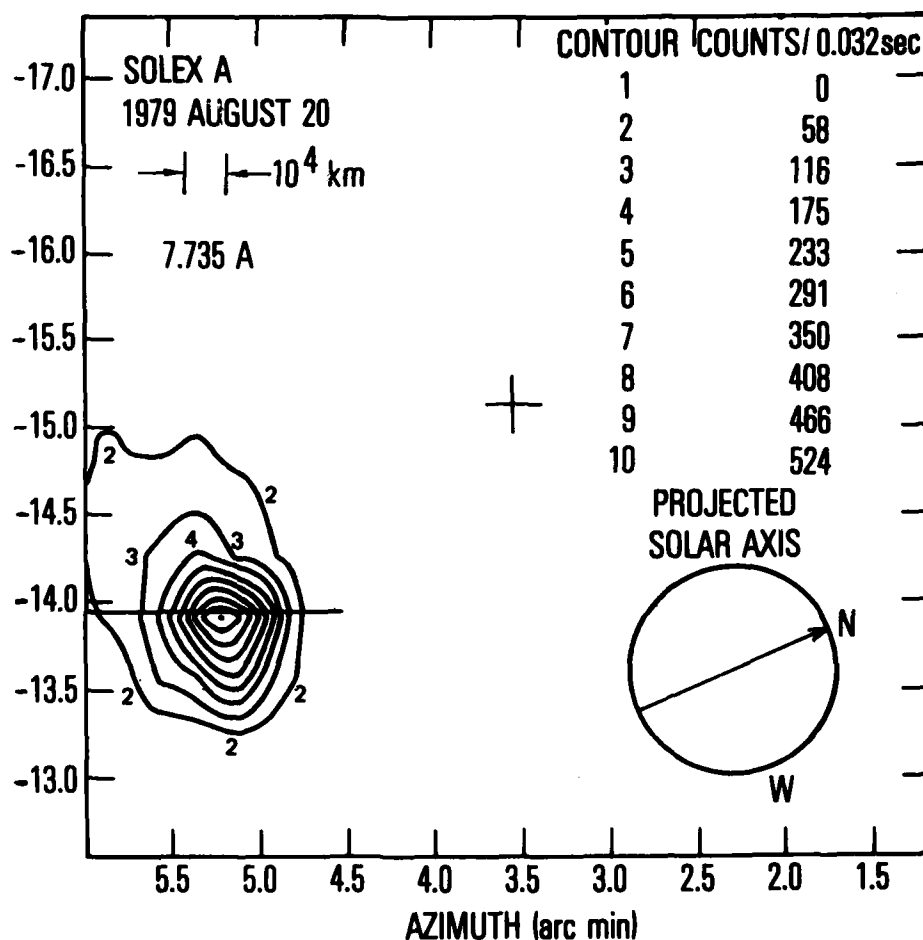


Fig. 7. Small Raster Solar Map in the 7.735 Å Continuum Made with the SOLEX A 20 Arc Sec Collimator. The raster, consisting of 16 horizontal lines, started at 09<sup>h</sup>12<sup>m</sup>12.26<sup>s</sup> UT and stopped 61.44 sec later. The raster center (cross) is located at solar latitude N 11.2° and solar longitude E 80.5°, with the solar north direction indicated. Elevation and azimuth scales in the figure are with respect to the center of the solar disk. Intensity levels are in counts/32 msec. Raster line number 12, the one with the highest count rates, is also shown.

### III. MONEX

The MONEX Monitor X-ray experiment records emission from the entire sun. A pair of proportional counters are used as detectors [5].

The LEM Low-Energy Monitor MONEX A module records 6 channels of pulse-height information in the 1 through 18 keV range every 1.024 sec and also records the 6-channel sum every 32 msec [15]. The soft X-ray flux measured by the LEM provides a quick-look measure of solar activity, to separate the spectral and temporal effects in the SOLEX and SOLFLEX flare measurements, and to determine flare line-to-continuum ratios.

The HEM High-Energy Monitor MONEX B module records 6 channels of pulse-height information in the 18 through 230 keV range every 1.024 sec, as well as all counts in this range every 32 msec. A sample MONEX B plot, which shows the hard X-ray development of the 8 April 1980 flare discussed earlier, is given in Figure 8. Unlike many hard X-ray events observed by the HEM, this event shows little enhancement above 59 keV. The temporal and spectral structure of solar X-ray bursts are studied with the HEM. The HEM is also used to automatically turn off the SOLEX detectors whenever large charged particle fluxes are present [4].

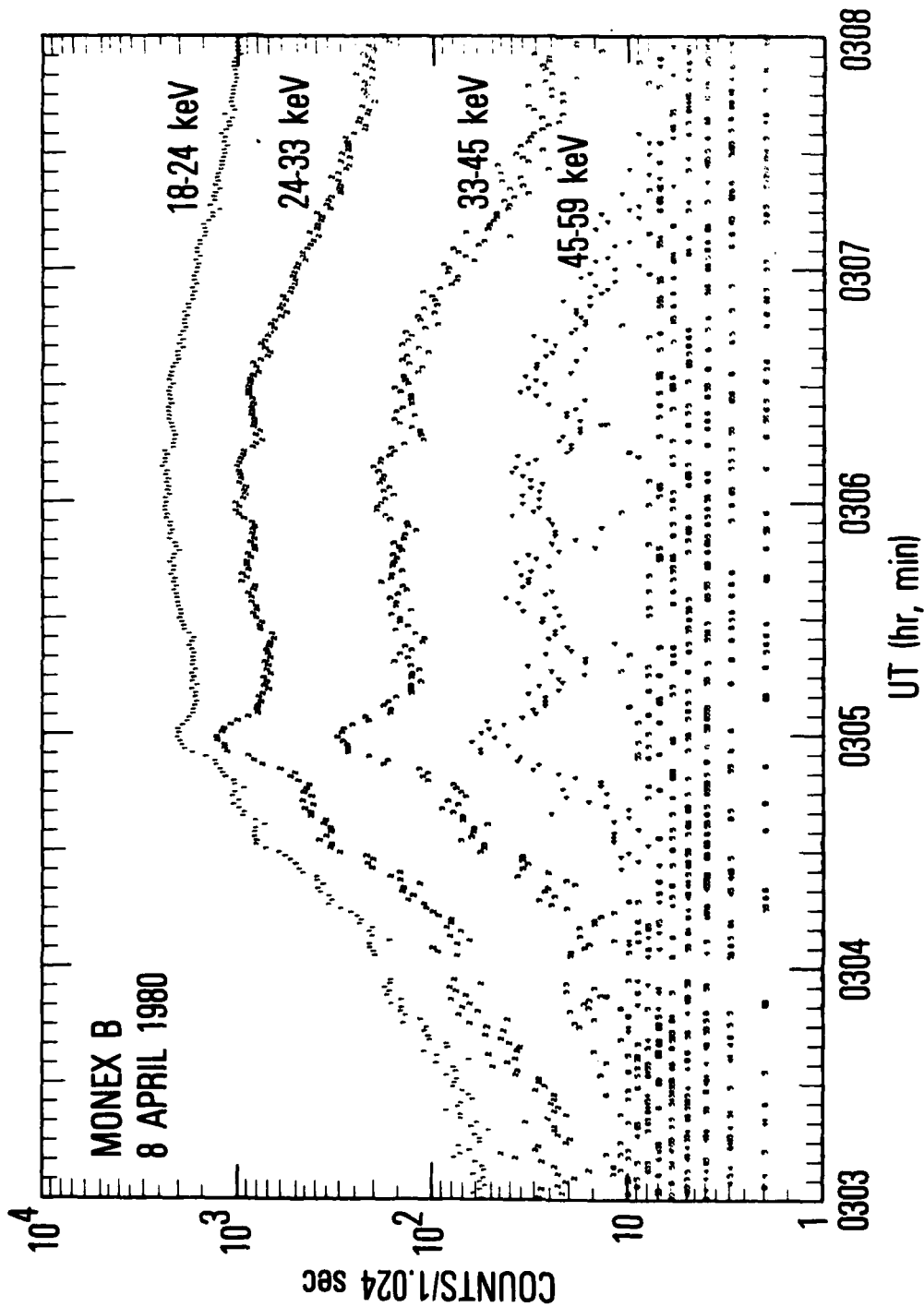


Fig. 8. MONEX High-Energy Monitor Data. The development of the 8 April 1980 flare in six energy channels in the range 18 through 230 keV is shown. The time resolution is 1.024 sec.

#### IV. SOLFLEX

The SOLFLEX Solar Flare X-ray experiment consists of four Bragg crystal spectrometers designed to record high-resolution spectra of diagnostically important X-ray emission lines produced in multimillion degree ( $>10^7$  K) coronal flare plasmas. The wavelength ranges observed are 1.82 through 1.97 Å, 2.98 through 3.07 Å, 3.14 through 3.24 Å, and 8.26 through 8.53 Å. The 1.82 through 1.97 Å region covers 1s-2p emission from Fe XXV and lower degrees of ionization. Most of the lines of Fe XXIV and lower ionization stages are produced by dielectronic recombination. The intensities of these lines relative to lines produced by electron impact innershell excitation are quite sensitive to electron temperature, while other line ratios using lines produced by innershell excitation can be used to determine the state of ionization equilibrium in the plasma. The 2.98 through 3.07 Å region contains the Lyman-α Ca XX lines (1s  $^2S_{1/2}$ -2p  $^2P_{1/2,3/2}$ ) and associated satellite lines produced by dielectronic recombination and innershell excitation. The 3.14 through 3.24 Å region contains the lines of Ca XIX and satellite lines of Ca XVIII and Ca XVII. Finally, the 8.26 through 8.53 Å region contains the Mg XII Lyman-α lines and lines of Fe XXIV and Fe XXIII, resulting from the transitions 2p  $^2P_{3/2}$  - 4d  $^2D_{5/2}$  and 2s $^2$   $^1S_0$  - 2s4p  $^1P_1$ . These long-wavelength lines provide an additional temperature diagnostic and information on the cooler component of the flare plasma.

Flat Ge (2d = 4.00 Å) crystals are used for  $\lambda < 4$  Å. The rocking curve FWHM of the crystals near 3 Å is  $\approx 30$  arc sec, while the FWHM of the iron-line crystal is 14 arc sec. Also, most flares have an angular extent of  $<40$  arc

sec [15,16]. Since the observed lines are produced at temperatures  $>10^7$  K, the angular widths of spectral lines due to thermal broadening are greater than the source size and the instrumental rocking-curve widths, and thus intrinsic line profiles can be determined. A similar remark holds for the long-wavelength crystal, which is ADP ( $2d = 10.64 \text{ \AA}$ ) with a rocking-curve width of about 32 arc sec.

These uncollimated crystals are mounted vertically on a common shaft and simultaneously observe the four wavelength regions. The shaft is rotated in angular steps of about 20 arc sec and a spectral scan consists of 450 steps. In operation the crystals scan their wavelength ranges back and forth continuously. Four scan speeds are possible: 1, 4, 8 or 16 steps/sec. The X-rays are detected by four proportional counters that are fixed in position.

A sample SOLFLEX spectrum recorded on 8 April 1980 is given in Figure 9. Derived temperatures are shown in Figure 4 [12]. Typical SOLFLEX spectra for a class M 7.2 flare on 9 May 1980 are presented in Figure 10 [12]. Numerous SOLFLEX results concerning flare electron temperature, ionization equilibrium, turbulence and mass ejection have also been published [14,17-23].

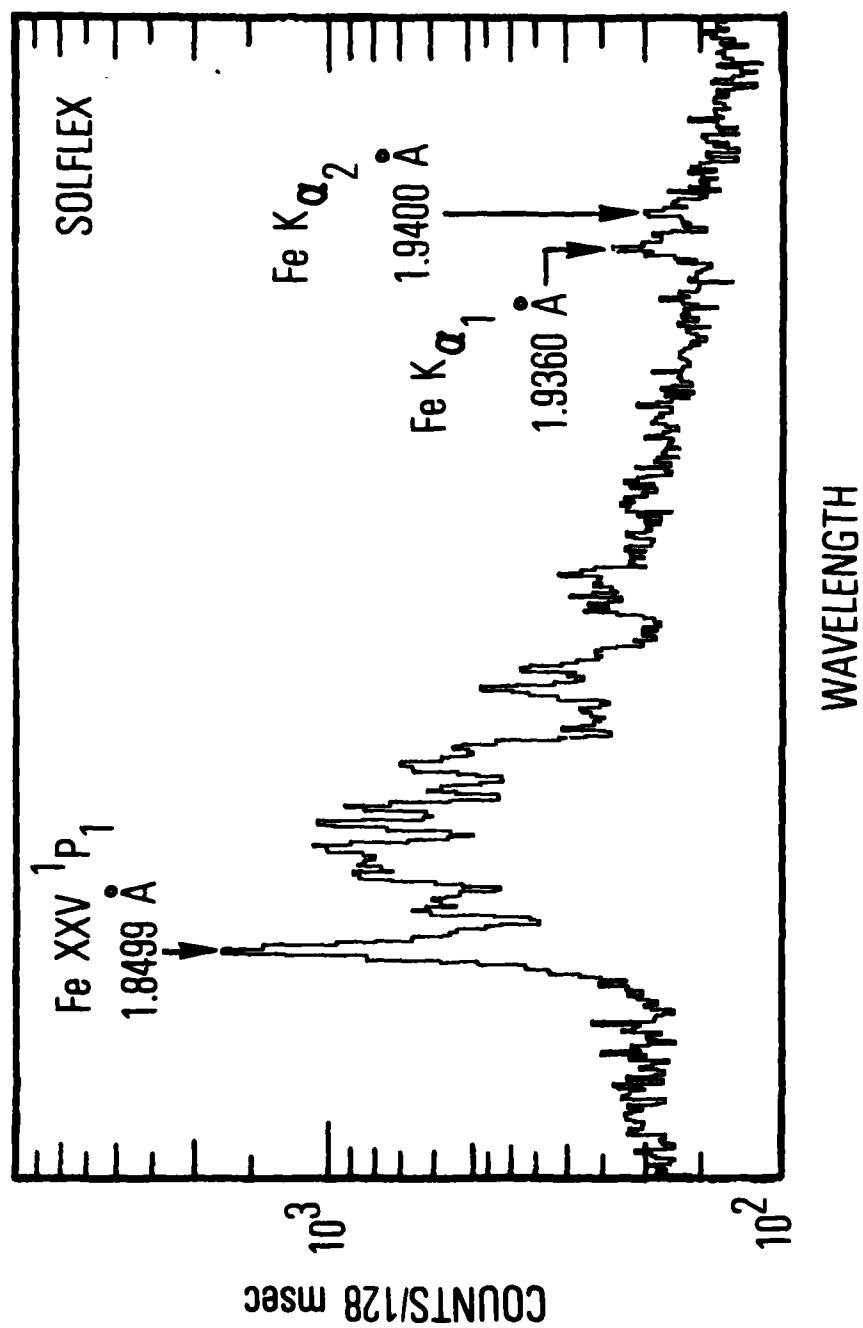


Fig. 9. Sample Fe SOLFLEX Spectrum of the 8 April 1980 Flare Recorded at 0307 UT.



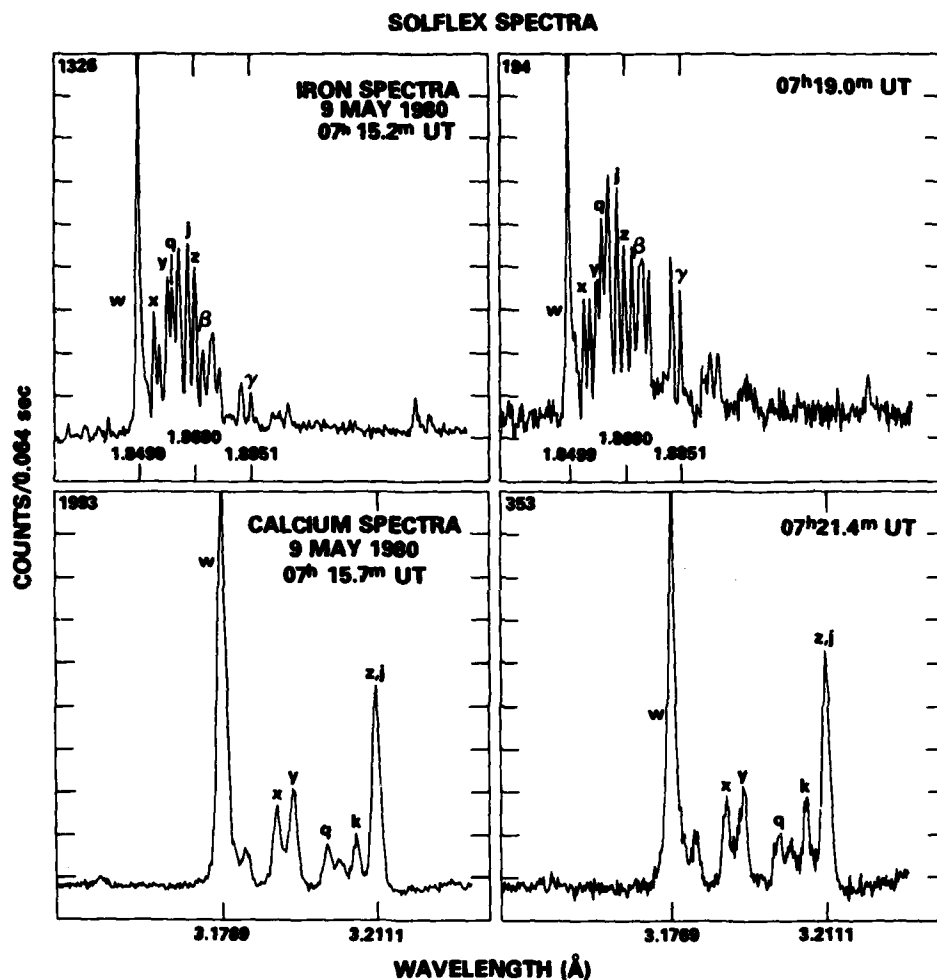


Fig. 10. Sample Fe and Ca SOLFLEX Spectra of the 9 May 1980 Event. Spectra near peak flux in the resonance line of Fe XXV (line w) are shown, as well as spectra recorded during the decay phase. The notation referring to the emission lines is defined in [18] and [20]. The numbers in the upper left hand corner of each panel are the peak counting rates for each ordinate scale.

## V. MAGMAP

The MAGMAP Magnesium Mapping experiment consists of two filtered proportional counters which view the sun through the SOLEX 60 arc sec collimator. This experiment makes relatively low spectral resolution maps of the solar X-ray emission (primarily line emission from Mg XI and XII) in the 8 through 12 Å spectral region. MAGMAP operates in the spacecraft large raster mode discussed earlier.

## VI. SOLWIND

The SOLWIND Solar Wind experiment is a modified Lyot white light coronagraph which artificially eclipses the sun by means of three small circular disks held in front of the instrument. After being focused, filtered and polarized, the image is recorded by an SEC Vidicon. SOLWIND images the sun's outer corona (2.5 through 10  $R_s$ ) in the spectral bandpass 4000 through 7000 Å with a spatial resolution of 1.25 arc min and a typical temporal resolution of 10 min. Coronal variations from 10 min to 27 days have been revealed with gray-scale difference images [24-29]. Figure 11 shows the great solar eruption on 24 May 1979 [30]. The radial velocity quickly accelerates from 350 km/sec at 2.7  $R_s$  to a nearly constant value of 700 km/sec between 3 and 10  $R_s$ . An interesting feature of this eruption is that the prominence retained its bright coronal loop structure while expanding by more than an order of magnitude. SOLWIND has observed radial velocities as high as 1000 km/sec. Frequent transient mass releases of up to  $10^{13}$  kg of solar plasma have also been observed, widely distributed in heliographic latitude. Since the corona can be considered the base of the solar wind, an understanding of the dynamical processes in the corona can lead to an understanding of the boundary conditions associated with the solar wind.

Additional topics currently being investigated include (1) a study of the relationship between coronal mass ejections and shocks observed in the solar wind by the Helios spacecraft, and (2) the measurement of the magnetic field in the corona. Of the 24 shocks seen by the Helios spacecraft when they both were within  $\pm 45^\circ$  from either solar limb, nearly all have been identified with

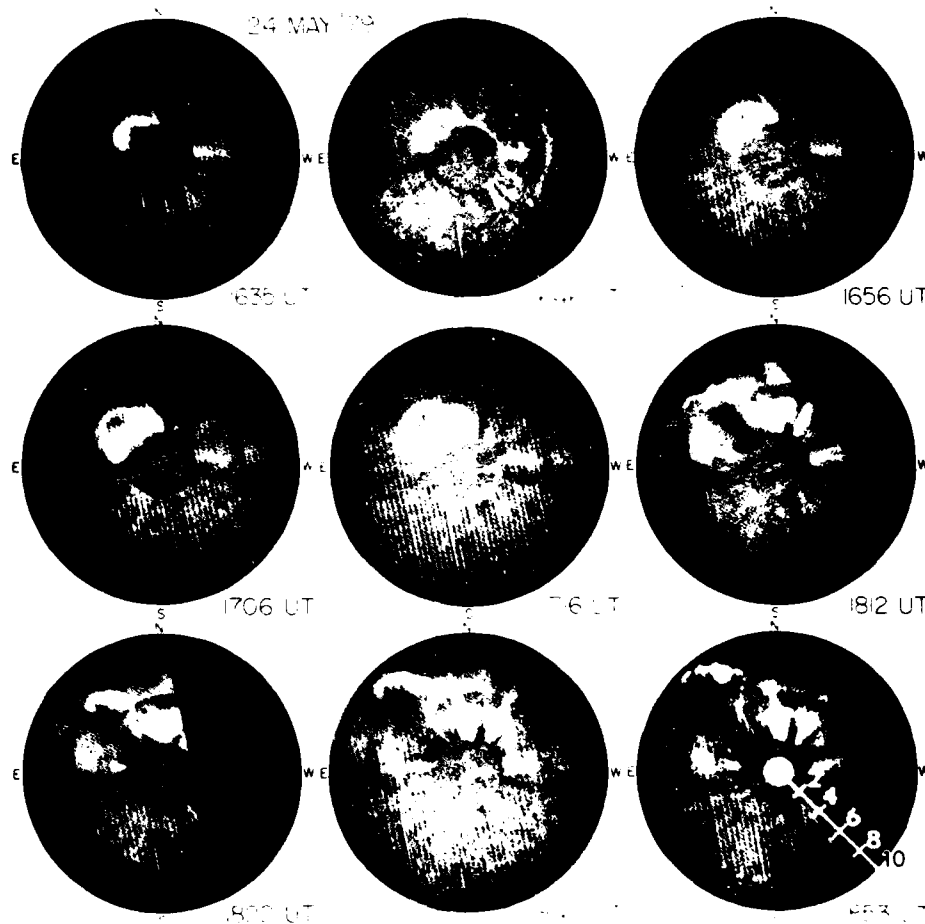


Fig. 11. Series of SOLWIND Images Showing the Changes in the Sun's Outer Corona Associated with a Very Large Eruptive Prominence. The prominence can be distinguished from the corona both by its characteristic finer detail and by the fact that its intensity was not reduced by the polarization analyzer rings that are faintly visible against the corona at 5 and 8  $R_s$ . The 4000 through 7000 Å bandpass shows the corona as strongly polarized Thomson-scattered photospheric emission and the prominence as relatively unpolarized H $\alpha$  6563-Å line emission. In the lower right image, the white area indicates the size of the solar disk, and the scale is marked in solar radii.

a coronal mass ejection event observed by SOLWIND. The coronal magnetic field is obtained by combining the coronagraph data with the measurement of the Faraday rotation of a linearly polarized signal such as that produced by a pulsar or spacecraft transmitter as it passes through the corona. A preliminary result from this study is that the average magnetic field in a coronal streamer at  $5R_S$  is about 1.2 mGauss.

## VII. SUMMARY

Since launch, each of the solar payloads on the P78-1 satellite has in general recorded 7 to 15 hours of solar data every 24 hours. Since all payloads are still working, an enormous data base has been accumulated. Collaborations with other Solar Maximum Year observers are encouraged. The contact for SOLEX and MONEX is P. B. Landecker, Aerospace Corporation, P. O. Box 92957, Los Angeles, California 90009, USA. Write to R. W. Kreplin about SOLFLEX and MAGMAP at the Naval Research Laboratory (Code 4175), Washington, D.C. 20375, USA. Finally, for SOLWIND data queries should be addressed to D. J. Michels, Code 4143, also at the Naval Research Laboratory.

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#### LABORATORY OPERATIONS

The Laboratory Operations of The Aerospace Corporation is conducting experimental and theoretical investigations necessary for the evaluation and application of scientific advances to new military space systems. Versatility and flexibility have been developed to a high degree by the laboratory personnel in dealing with the many problems encountered in the nation's rapidly developing space systems. Expertise in the latest scientific developments is vital to the accomplishment of tasks related to these problems. The laboratories that contribute to this research are:

Aerophysics Laboratory: Launch vehicle and reentry aerodynamics and heat transfer, propulsion chemistry and fluid mechanics, structural mechanics, flight dynamics; high-temperature thermomechanics, gas kinetics and radiation; research in environmental chemistry and contamination; cw and pulsed chemical laser development including chemical kinetics, spectroscopy, optical resonators and beam pointing, atmospheric propagation, laser effects and countermeasures.

Chemistry and Physics Laboratory: Atmospheric chemical reactions, atmospheric optics, light scattering, state-specific chemical reactions and radiation transport in rocket plumes, applied laser spectroscopy, laser chemistry, battery electrochemistry, space vacuum and radiation effects on materials, lubrication and surface phenomena, thermionic emission, photosensitive materials and detectors, atomic frequency standards, and bioenvironmental research and monitoring.

Electronics Research Laboratory: Microelectronics, GaAs low-noise and power devices, semiconductor lasers, electromagnetic and optical propagation phenomena, quantum electronics, laser communications, lidar, and electro-optics; communication sciences, applied electronics, semiconductor crystal and device physics, radiometric imaging; millimeter-wave and microwave technology.

Information Sciences Research Office: Program verification, program translation, performance-sensitive system design, distributed architectures for spaceborne computers, fault-tolerant computer systems, artificial intelligence, and microelectronics applications.

Materials Sciences Laboratory: Development of new materials: metal matrix composites, polymers, and new forms of carbon; component failure analysis and reliability; fracture mechanics and stress corrosion; evaluation of materials in space environment; materials performance in space transportation systems; analysis of systems vulnerability and survivability in enemy-induced environments.

Space Sciences Laboratory: Atmospheric and ionospheric physics, radiation from the atmosphere, density and composition of the upper atmosphere, aurorae and airglow; magnetospheric physics, cosmic rays, generation and propagation of plasma waves in the magnetosphere; solar physics, infrared astronomy; the effects of nuclear explosions, magnetic storms, and solar activity on the earth's atmosphere, ionosphere, and magnetosphere; the effects of optical, electromagnetic, and particulate radiations in space on space systems.